UNIVERSITI TEKNOLOGI MARA

5th I-CReST 2025

INTERNATIONAL CONFERENCE ON RESEARCH AND PRACTICES IN SCIENCE, TECHNOLOGY AND SOCIAL SCIENCES

SYNERGY FOR FUTURE SUSTAINABILITY:
BRIDGING SCIENCE, TECHNOLOGY AND HUMANITIES

Proceeding Book

UNIVERSITI TEKNOLOGI MARA
CAWANGAN SELANGOR, KAMPUS DENGKIL
MALAYSIA

13th SEPTEMBER 2025

ORGANISED BY: Centre of Foundation Studies

STRATEGIC PARTNER: UiTM Global

IN COLLABORATION WITH: UTM

I-CReST 2025: 144-107 – Raman and CHNS-Based Elucidation of Carbon Development in Banana Peel Biomass for Sustainable Carbon Materials

Haslinawati Mohd Mustapha[1]*, Fadzidah Mohd Idris[2], Affa Rozana Abdul Rashid[3]

[1]*Pusat Tamhidi, Universiti Sains Islam Malaysia, 71800 Bandar Baru Nilai, Nilai, Negeri Sembilan, Malaysia.*
[2]*Kolej Permata Pintar, Universiti Sains Islam Malaysia, 71800 Bandar Baru Nilai, Nilai, Negeri Sembilan, Malaysia.*
[3]*Faculty of Science and Technology, Universiti Sains Islam Malaysia, 71800 Bandar Baru Nilai, Nilai, Negeri Sembilan, Malaysia.*

*E-mail: haslinawati@usim.edu.my

ABSTRACT

The growing demand for sustainable materials in environmental and energy applications has led to increased interest in agricultural waste, particularly for producing activated carbon (AC). While conventional AC is derived from non-renewable sources like coal and petroleum coke, agricultural biomass such as banana peels offers a green and sustainable alternative due to its rich lignocellulosic content. This study investigates the carbon development characteristics of banana peel biomass through Raman Spectroscopy and CHNS elemental analysis. Banana peels, an abundant agriculture waste, were thermochemically treated and analyzed to evaluate their potential as a carbon rich material for energy and material applications. Raman Spectroscopy was used to assess the structural evolution of carbon, particularly focusing on the D and G bands, which reflect disorder and graphitic characteristics, respectively. The intensity ratio (I_D/I_G) revealed a progressive transformation of amorphous carbon to more ordered structures with increasing carbonization temperature. Complementarily, CHNS analysis quantified the elemental composition of carbon (C), hydrogen (H), nitrogen (N), and sulfur (S). The correlation between structural by Raman Spectroscopy and compositional analysis by CHNS data underscores the potential of banana peel biomass as a sustainable precursor activated carbon, or carbon-based nanomaterials. This integrative research provides a better knowledge of biomass carbonisation routes and promotes the value-added use of agricultural waste.

Keywords: Agriculture waste; banana peels; activated carbon

1. INTRODUCTION

The ongoing search for sustainable and economically feasible materials for advanced applications, particularly in environmental remediation and energy storage, has accelerated research into agricultural waste products [1,2]. Due to its large specific surface area, varied surface chemistry, and adjustable porosity, activated carbon (AC) is a well-known adsorbent. However, traditionally it is relied on non-renewable fossil-based precursors like coal and petroleum coke [3]. There are concerns that these resources will gradually deplete or eventually run out due to continuous usage. Therefore, there is a need to seek alternative options that are more environmentally friendly (green) and sustainable in the long term [4]. Therefore, agricultural biomass waste presents a viable option for production activated carbon. Bananas are among the most consumed fruits worldwide, resulting in significant quantities of banana

peels as a lignocellulosic waste product, which frequently contributes to landfill burden and environmental damage [5]. The chemical composition of banana peels are rich in cellulose, hemicellulose, and lignin which provide an excellent basis for the production of activated carbon with an unique porosity structure [6, 7]. Recent advances in the synthesis and characterisation of banana-peel-derived activated carbon (BPAC) have demonstrated its tremendous promise in a variety of important applications. For example, in wastewater treatment, BPAC has demonstrated outstanding performance in adsorbing a variety of contaminants, including heavy metals, dyes, organic micropollutants and inorganic anions [8, 9, 10]. Beyond its use in environmental applications, BPAC is also becoming more popular in the energy storage area. Because of its distinctive porous design and high electrical conductivity, it shows promise as an electrode material in lithium-ion batteries and supercapacitors [1, 2, 12, 13].

This study investigates the carbon development in activated carbon derived from banana peels, with emphasis on CHNS elemental analysis and Raman spectroscopy. Through these characterizations, the paper aims to elucidate the structural and compositional evolution of the material, reinforcing the role of agricultural waste valorization in advancing sustainable carbon-based materials.

2. LITERATURE REVIEW

2.1 Global Banana Production and Waste Generation

Bananas are a staple food crop globally, with annual production exceeding 120 million tonnes, making them one of the most consumed fruits worldwide. Consequently, the processing and consumption of bananas generate enormous quantities of lignocellulosic waste, primarily in the form of banana peels, which constitute approximately 30-40% of the fruit's total weight [14, 15]. For instance, countries like India, China, Indonesia, and Brazil are major producers, contributing significantly to this biomass waste [16]. The disposal of these peels often involves landfilling or open burning, leading to environmental issues such as greenhouse gas emissions, leachate formation, and aesthetic pollution [14, 17]. This substantial and readily available waste stream presents a compelling economic and environmental incentive for its conversion into value-added products, aligning with global sustainable development goals.

2.2 Compositional Analysis of Banana Peels

The suitability of banana peels as a precursor for activated carbon is underpinned by their unique biochemical composition. Banana peels are primarily composed of carbohydrates (cellulose, hemicellulose), lignin, pectin, and minor amounts of proteins, lipids, and minerals [6]. Typically, cellulose accounts for 15-20%, hemicellulose for 10-15%, and lignin for 6-12% of the dry weight, though these proportions can vary depending on the banana variety, ripeness, and geographical location [7]. This lignocellulosic matrix provides a robust carbonaceous framework that can be effectively converted into a porous carbon material through various thermochemical processes [18]. The presence of inherent minerals, such as potassium, can also play a catalytic role during the activation process, influencing the final pore structure and surface chemistry of the derived activated carbon [19]. Recent studies have further elaborated on the distribution and accessibility of these components, informing more efficient pre-treatment and activation strategies [6].

2.3 Synthesis Methods for Banana-Peel-Derived Activated Carbon

The production of activated carbon from banana peels typically involves two main stages: carbonization and activation. Carbonization, usually carried out under inert atmosphere at elevated temperatures, converts the raw biomass into a carbonaceous char. Subsequent activation develops the porous structure and enhances the surface area. The choice of activation method significantly influences the final properties of the BPAC.

2.3.1 Physical Activation

Physical activation commonly employs gases such as steam, carbon dioxide (CO_2), or a combination of both at high temperatures (typically 600-900 °C). Steam activation is highly effective in developing a well-defined porous structure due to the gasification reaction between steam and the carbon matrix [20]. For example, a recent study by Hendronursito et al. (2025) demonstrated that a two-step hydrothermal pre-treatment followed by steam activation yielded highly porous activated carbon from banana peels, achieving significant surface areas [6]. CO_2 activation, on the other hand, is known for creating narrower pores and is often preferred for applications requiring microporosity [21]. Combinations of CO_2 and steam have also been explored to optimize pore size distribution and surface functionality, balancing the advantages of both methods [22]. The primary advantage of physical activation lies in its simplicity and the avoidance of chemical residues, although it often requires higher activation temperatures and longer activation times compared to chemical activation [23].

2.3.2 Chemical Activation

Chemical activation involves impregnating the banana peel precursor with activating agents such as phosphoric acid (H_3PO_4), potassium hydroxide (KOH), zinc chloride ($ZnCl_2$), or potassium carbonate (K_2CO3), followed by carbonization at lower temperatures (typically 400-700 °C) [24]. Among these, H_3PO_4 is widely utilized due to its ability to act as a dehydrating agent, promoting char formation and inhibiting tar production, while simultaneously creating a well-developed pore structure [25]. Tripathy et al. (2021) successfully prepared BPAC using H3PO4 activation, achieving an activated carbon with excellent supercapacitive performance [3]. KOH activation is known for generating high surface areas and well-developed microporosity, often producing AC with superior adsorption capacities [26]. A recent study by Olaoye et al. (2018) employed chemical activation with different agents, including KOH, to assess the efficacy of BPAC in removing cyanide and heavy metals from wastewater [5]. The chemical agent acts by promoting dehydration, cracking, and rearrangement of the carbon structure, as well as serving as a template for pore formation [24]. A key advantage of chemical activation is the lower activation temperature, which can reduce energy consumption, but it often necessitates extensive washing to remove residual chemicals [23]. Recent research continues to refine chemical activation processes, exploring novel activating agents or combinations to optimize pore characteristics and surface functionality for specific applications [27].

3. METHODOLOGY

3.1 Raw Material Preparation

Banana peels from the *Musa* × *paradisiaca* cultivar 'Pisang Nangka' were used as the raw precursor for activated carbon synthesis. The peels were cut into small pieces and placed on an aluminum tray, then dried in a convection oven at 140 °C for 8 hours.
The dried banana peels were ground using a ball mill at 450 rpm for 1 hour and 10 minutes, with alternating clockwise and counterclockwise rotation to ensure homogeneous particle size reduction. The resulting powder was soaked in pure ethanol for 30 minutes and left under a fume hood. After soaking, the sample was filtered and left to dry overnight (approximately 18 to 24 hours), followed by further drying in a drying cabinet for 3 hours at room temperature.

3.2 Chemical Activation and Carbonization

The dried banana peel powder was mixed with activating agents Zinc Chloride ($ZnCl_2$) and Ferric Chloride ($FeCl_3$) in a 1:3 weight ratio. A total of three samples were prepared to study the effects of different activating agents ($ZnCl_2$ or $FeCl_3$) on the carbon development.

The impregnated samples were then placed in a ceramic crucible and subjected to carbonization in a muffle furnace under limited air conditions. The samples were heated at the designated temperatures (500°C) for 1 hour with a heating rate of 10 °C/min.

3.3 Washing and Drying

After carbonization, the samples were washed repeatedly with 0.1 M Hydrochloric acid (HCl) to remove residual inorganic salts and activating agents, followed by multiple rinses with distilled water until the filtrate reached a neutral pH. The washed activated carbon samples were then dried at 110 °C for 12 hours and stored in airtight containers for further analysis.

4. RESULTS AND DISCUSSION

4.1 CHNS Elemental Analysis

According to elemental analysis (Table 1), the carbon, nitrogen, and hydrogen content of the carbonised banana peel samples varied significantly, depending on the activating agent used. A high carbon concentration of 67.42% was found in the untreated raw banana peel that pyrolyzed at 500°C. The nitrogen and hydrogen percentages were 2.77% and 2.585%, respectively.
The carbon concentration dramatically dropped to 46.88% after chemical activation with $ZnCl_2$, accompanied by a slight increase in nitrogen (2.93%) and hydrogen (3.085%). The decrease in carbon indicates that the lignocellulosic structure was partially broken-down during pyrolysis, most likely as a result of dehydration and aromatisation events brought on by $ZnCl_2$, which encourage the formation of porosity. On the other hand, slight enhancement of nitrogen content indicates that $ZnCl_2$ may stabilize nitrogen-containing functional groups during thermal treatment. This is valuable for electrochemical applications, as nitrogen doping can host surface defects and pseudocapacitive behavior. Furthermore, the higher hydrogen concentration implies that $ZnCl_2$ activation might retain some volatile organic fragments or functional groups, which could improve electrolyte accessibility and surface wettability.

In contrast, the sample activated with $FeCl_3$ showed the lowest carbon (37.03%), nitrogen (1.65%), and hydrogen (1.693%) content, indicating a more aggressive activation process. This suggests that $FeCl_3$ promotes extensive decomposition of organic material and functional groups, leading to a more graphitized but less functionalized carbon structure. However, $FeCl_3$

introduces redox-active sites, which can enhance pseudocapacitive performance in supercapacitor applications.

Table 1. CHNS elemental analysis of BP samples

Samples	Carbon (%)	Nitrogen (%)	Hydrogen (%)
Untreated raw banana peel	67.42	2.77	2.585
Banana peel + $ZnCl_2$	46.88	2.93	3.085
Banana peel + $FeCl_3$	37.03	1.65	1.693

4.2 Raman Spectroscopy

The structural characteristics and level of graphitisation of the carbon materials made from raw banana peel and those activated with $ZnCl_2$ and $FeCl_3$ at 500°C were examined using Raman spectroscopy. The D band (~1340 cm^{-1}) and the G band (~1590 cm^{-1}) are the two noticeable peaks present in all samples. The graphitic (sp^2 hybridized) domains in the carbon framework are represented by the G band, whereas disordered carbon or structural flaws or defects (sp^3 hybridized carbon) are linked to the D band.

With a value of ID/IG ratio roughly 0.85, which represents the relative level of disorder in the carbon matrix, was constant across all samples. This implies that, despite chemical treatment, the three samples (untreated raw banana peel, $ZnCl_2$ activated banana peel, and $FeCl_3$ activated banana peel) have a comparable level of structural disorder. Since 0.85 is less than 1, indicates that all these three samples have a more ordered, graphitic structure than they are disordered. However, the ratio is not extremely low, which suggests there is still a significant amount of disorder present. These results highlight the material's potential as a promising electrode candidate for energy storage applications, particularly in supercapacitors.

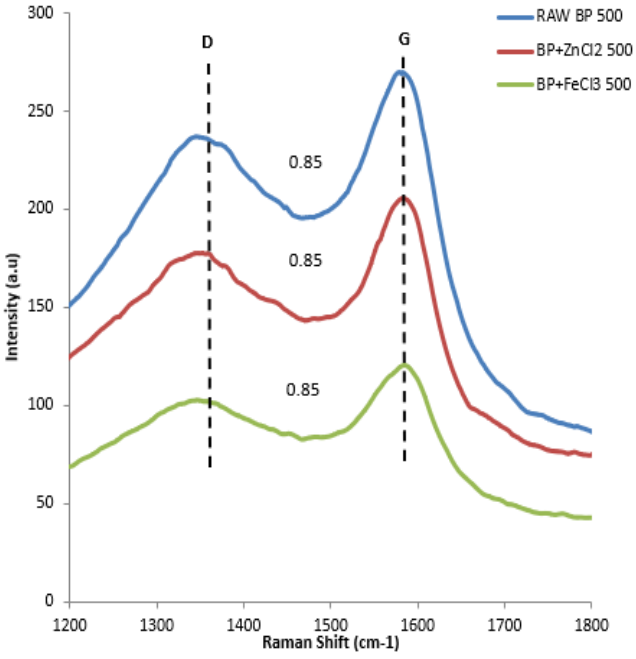

Fig. 1. Raman spectra of BP samples

5. CONCLUSION

This study demonstrates the significant influence of chemical activation agents on the elemental composition and structural characteristics of carbonised banana peel-derived materials. Pyrolysis at 500°C yielded carbon-rich biochar from untreated banana peel, while activation with $ZnCl_2$ and $FeCl_3$ introduced distinct modifications to the carbon matrix. $ZnCl_2$ treatment retained nitrogen and hydrogen, enhancing surface functionality and wettability, thus ideal for electrochemical applications. $FeCl_3$ activation led to deeper decomposition, yielding a graphitized structure with redox-active sites. Despite these differences, all samples showed a consistent ID/IG ratio (~0.85), indicating a moderately ordered carbon framework. These findings highlight the potential of banana peel-derived carbons as sustainable electrode materials for supercapacitors.

ACKNOWLEDGEMENT

The authors acknowledge the Universiti Sains Islam Malaysia for financial support through Research Grant Scheme (PPPI/USIM/TAMHIDI/USIM/112223).

REFERENCES

[1] Packirisamy, V., Ariyamuthu, R., Thangavelu, K., Murugesan, V. V., & Rugmangathan, J. (2025). Banana peel biomass–derived activated carbon for nickel ion removal and energy storage applications. Biomass Conversion and Biorefinery. https://doi.org/10.1007/s13399-025-06703-5

[2] Tadesse, M. G., Kasaw, E., & Lübben, J. F. (2023). Valorization of banana peel using carbonization: Potential use in the sustainable manufacturing of flexible supercapacitors. Micromachines, 14(2), 330. https://doi.org/10.3390/mi14020330

[3] Tripathy, A., Mohanty, S., Nayak, S. K., & Ramadoss, A. (2021). Renewable banana-peel-derived activated carbon as an inexpensive and efficient electrode material showing fascinating supercapacitive performance. Journal of Environmental Chemical Engineering, 9(6), 106398. https://doi.org/10.1016/j.jece.2021.106398

[4] Luna-Lama, F., Morales, J., & Caballero, A. (2021). Biomass Porous Carbons Derived from Banana Peel Waste as Sustainable Anodes for Lithium-Ion Batteries. Materials, 14(20), 5995. https://doi.org/10.3390/ma14205995

[5] Olaoye, R., Afolayan, O., Mustapha, O., & Adeleke, H. (2018). The Efficacy of Banana Peel Activated Carbon in the Removal of Cyanide and Selected Metals from Cassava Processing Wastewater. Advances in Research, 16(1), 1–12. https://doi.org/10.9734/air/2018/43070

[6] Hendronursito, Y., Astuti, W., Sabarman, H., & Santoso, I. (2025). A porous carbon active derived from banana peel by hydrothermal activation two-step methods. International Journal of Renewable Energy Development. https://doi.org/10.61435/ijred.2025.60847

[7] Boyle, O., Xiao, B., & Mangwandi, C. (2025). Valorization of Banana Peel Waste into Advanced Adsorbent Beads for the Removal of Emerging Pollutants from Wastewater. Materials, 18(5), 1084. https://doi.org/10.3390/ma18051084

[8] Ambaye, T. G., Vaccari, M., Van Hullebusch, E. D., Amrane, A., & Rtimi, S. (2020). Mechanisms and adsorption capacities of biochar for the removal of organic and inorganic pollutants from industrial wastewater. International Journal of Environmental Science and Technology, 18(10), 3273–3294. https://doi.org/10.1007/s13762-020-03060-w

[9] Al-Sareji, O. J., Grmasha, R. A., Meiczinger, M., Al-Juboori, R. A., Somogyi, V., & Hashim, K. S. (2024). A Sustainable Banana Peel Activated Carbon for Removing Pharmaceutical Pollutants from Different Waters: Production, Characterization, and Application. Materials, 17(5), 1032. https://doi.org/10.3390/ma17051032

[10] Abdulfatai, J., Saka, A. A., Afolabi, A. S., & Micheal, O. (2012). Development of Adsorbent from Banana Peel for Wastewater Treatment. Applied Mechanics and Materials, 248, 310–315. https://doi.org/10.4028/www.scientific.net/amm.248.310

[11] Channei, D., Jannoey, P., Thammaacheep, P., Khanitchaidecha, W., & Nakaruk, A. (2025). From Waste to Value: Banana-Peel-Derived Adsorbents for Efficient Removal of Polar Compounds from Used Palm Oil. Applied Sciences, 15(4), 2205. https://doi.org/10.3390/app15042205

[12] Taer, E., Taslim, R., Aini, Z., Hartati, S. D., & Mustika, W. S. (2017). Activated carbon electrode from banana-peel waste for supercapacitor applications. AIP Conference Proceedings. https://doi.org/10.1063/1.4973093

[13] Tadesse, M. G., Kasaw, E., & Lübben, J. F. (2023b). Valorization of banana peel using carbonization: Potential use in the sustainable manufacturing of flexible supercapacitors. Micromachines, 14(2), 330. https://doi.org/10.3390/mi14020330

[14] Bishnoi, S., Sharma, S., Agrawal H. (2023). Exploration of the Potential Application of Banana Peel for Its Effective Valorization: A Review, Indian Journal of Microbiology, 63, 398-409.

[15] Giwa, A. S., Sheng, M., Maurice, N. J., Liu, X., Wang, Z., Fengmin, C., Huang, B., & Wang, K. (2023). Biofuel Recovery from Plantain and Banana Plant Wastes: Integration of Biochemical and Thermochemical Approach. JOURNAL OF RENEWABLE MATERIALS, 11(6), 2593–2629. https://doi.org/10.32604/jrm.2023.026314.

[16] Torgerson, A. M. (2009). Fair trade banana production in the Windward Islands: local survival and global resistance. Agriculture and Human Values, 27(4), 475–487. https://doi.org/10.1007/s10460-009-9246-1

[17] Wani, K. M., & Dhanya, M. (2025). Unlocking the potential of banana peel bioactives: extraction methods, benefits, and industrial applications. Discover Food, 5(1). https://doi.org/10.1007/s44187-025-00276-y

[18] Adewale George Adeniyi, Iwuozor, K. O., Ebuka Chizitere Emenike, Sagboye, P. A., Kehinde Temitope Micheal, Taiwo Temitayo Micheal, Saliu, O. D., & James, R. (2023). Biomass-derived activated carbon monoliths: A review of production routes, performance, and commercialization potential. Journal of Cleaner Production, 423, 138711–138711. https://doi.org/10.1016/j.jclepro.2023.138711

[19] Niu, J., Miao, J., Zhang, H., Guo, Y., Li, L., & Cheng, F. (2022). Focusing on the impact of inherent minerals in coal on activated carbon production and its performance: The role of trace sodium on SO2 and/or NO removal. Energy, 263, 125638. https://doi.org/10.1016/j.energy.2022.125638

[20] Rodriguez-Reinoso, F. (1991). Controlled gasification of carbon and pore structure development. In Springer eBooks (pp. 533–571). https://doi.org/10.1007/978-94-011-3310-4-26

[21] Serafin, J., & Bartosz Dziejarski. (2023). Activated carbons—preparation, characterization and their application in CO2 capture: A review. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-023-28023-9

[22] Maya, J. C., Macías, R., Gómez, C. A., & Chejne, F. (2020). On the evolution of pore microstructure during coal char activation with steam/CO2 mixtures. Carbon, 158, 121–130. https://doi.org/10.1016/j.carbon.2019.11.088

[23] Sajjadi, B., Chen, W.-Y., & Egiebor, N. O. (2019). A comprehensive review on physical activation of biochar for energy and environmental applications. Reviews in Chemical Engineering, 35(6), 735–776. https://doi.org/10.1515/revce-2017-0113

[24] Azry Borhan, Subhashini Thangamuthu, Mohd Faisal Taha, & Amira Nurain Ramdan. (2015). Development of activated carbon derived from banana peel for CO2 removal. Nucleation and Atmospheric Aerosols. https://doi.org/10.1063/1.4928819

[25] Elmouwahidi, A., Bailón-García, E., Pérez-Cadenas, A. F., Maldonado-Hódar, F. J., & Carrasco-Marín, F. (2017). Activated carbons from KOH and H 3 PO 4 -activation of olive residues and its application as supercapacitor electrodes. Electrochimica Acta, 229, 219–228. https://doi.org/10.1016/j.electacta.2017.01.152

[26] Yu, J., Fu, N., Zhao, J., Liu, R., Li, F., Du, Y., & Yang, Z. (2019). High specific capacitance electrode material for supercapacitors based on Resin-Derived Nitrogen-Doped porous carbons. ACS Omega, 4(14), 15904–15911. https://doi.org/10.1021/acsomega.9b01916

[27] Sevilla, M., Díez, N., & Fuertes, A. B. (2021). More sustainable chemical activation strategies for the production of porous carbons. ChemSusChem, 14(1), 94-117.